ZEUS®

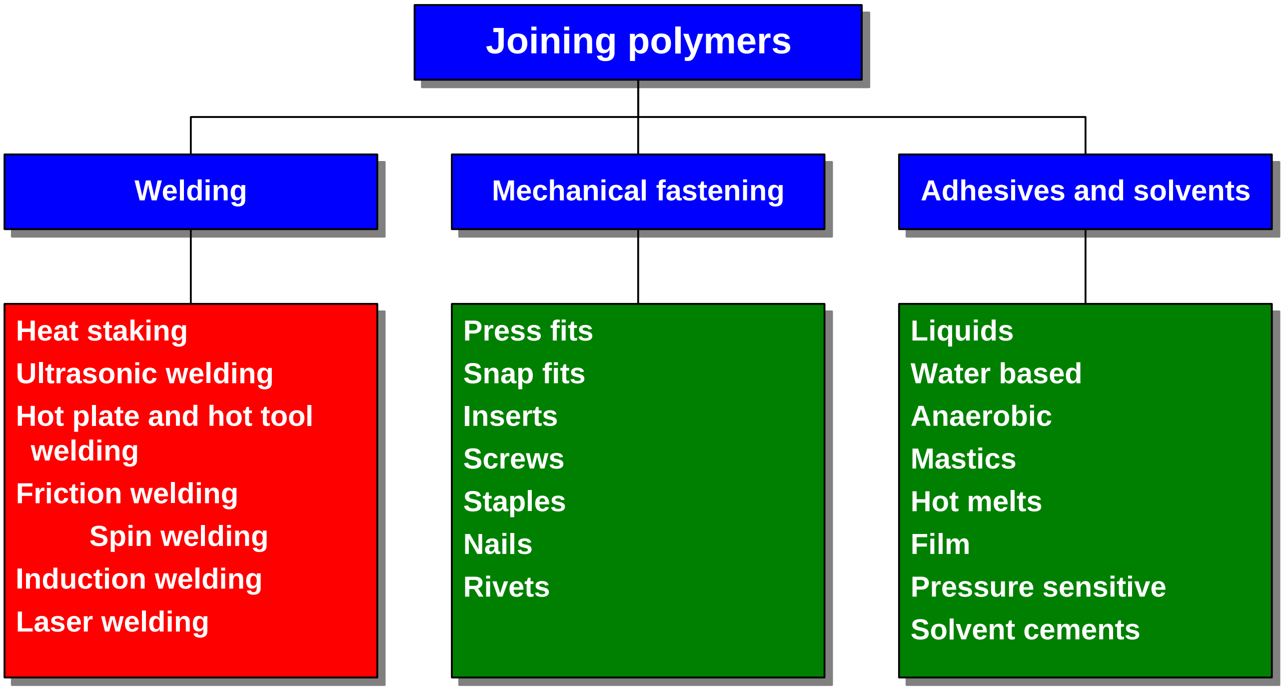
TECHNICAL WHITEPAPER

Welding Polymers

Introduction

When forming functional parts and objects, there is usually a need to join different materials together. With very few exceptions, this is also true for plastics. The wide range of possible joining methods represents a distinct advantage for the material. In fact, almost every conceivable joining method has been used with plastics.

Figure 1 summarizes the joining methods for plastics:



The basic joining methods for plastics

The joining of plastics is a very broad subject; therefore this whitepaper will focus solely on some of the ways to weld plastics. The remaining methods will be covered in future whitepapers.

Welding

Many plastics products are welded together to ensure they’re not disassembled, such as a vinyl window, where simple hot plate welding is used to form the corners. The thermoplastic nature of plastics means that welding can be used to melt the plastic and form a joint that is as strong as the parent material.

Heat staking

- Heat staking is the plastics equivalent of a permanent rivet and involves thermally softening a stake and then forming a rivet-like retaining head under pressure from a cold tool. The most common heat source for this procedure is hot air, and when it is used, the joining is called” hot air staking.”
- The stake is a low-cost yet integral part of the molding, and there is no need for any separate fastener. This proves to be beneficial, as there are no foreign materials to remove or sort, which can prove costly.

Hot air staking is a simple process:

1. The stake is heated by a current of hot air anywhere from 150°C to 400°C.
2. When the stake has reached its softening point, the heat source is withdrawn.
3. Then, a cold forming tool is used to form the rivet head and shape the stake to consolidate and join the parts.
4. Finally, the tool is removed when the rivet head has cooled enough to hold the joint.

For good load holding, it’s better to have several small stakes, as they can withstand heat better than larger ones, and they’re more malleable as well. When thick stakes must be used, the heat distribution can be improved by adding a V-shaped dimple to increase the heat transfer. For easier assembly, the clearance hole in the component to be riveted should be 10% greater than the stake diameter. In all cases, the forming height of the stake should be enough to completely form the rivet head, but it shouldn’t be so great that there is distortion during heating.

The shape of the forming tool determines the shape of the fully formed rivet head, and the volume of the forming tool cavity should be slightly less than that of the section of stake that is to be formed. This creates a compacting pressure, which ensures a fully formed head.

Heat staking can be used to join simple sheets, to support printed circuit board. Rollover staking can be used to secure springs, bearings, bushes and inserts.

Ultrasonic welding

In some ways, ultrasonic welding is similar to heat staking – however, ultrasonic energy is used as a heat source. Ultrasound is suitable for techniques such as spot welding, staking, inserting and swaging. Ultrasonic welding uses vibrations at frequencies from 15kHz to 40kHz to generate the heat that locally melts the plastic and forms a fusion weld.

The key part of an ultrasonic welder is a piezoelectric transducer (a PZT converter) that vibrates when a high frequency alternating current is applied. The vibrations produced by the PZT converter are small (0.01mm to 0.02mm) and are initially boosted by a tuned resonator to effectively double the amplitude of the vibrations. The vibrations must also be concentrated in the area where the weld is to be created, and this requires a “sonotrode” or ”horn” to focus the vibrations in the correct area. In order to provide the correct contact pressure, the horn concentrates and amplifies the ultrasonic vibrations (to the region of 0.05mm to 0.12mm) while in contact with the area that is to be welded.

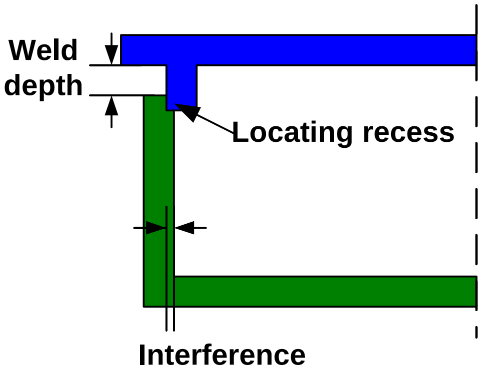
Horn design is very application-specific and requires a specialist’s knowledge of the parts and the process. One important aspect of horn design is the distinction between near and far-field welds: A near-field weld is where the joint is within about 6mm of a horn tip contact point, whereas anything else is a far-field weld. Far-field welding is less effective because of energy losses within the material.

Not all materials are well-suited to ultrasonic welding because not all materials equally transmit high-frequency vibrations. As general rules:

- Rigid materials are better than flexible materials.
- Amorphous materials are better than semi-crystalline materials.
- Far-field welding in semi-crystalline materials (such as fluoropolymers) generally gives poor results.
- Dissimilar plastics can be joined, but the difference in melt temperature between the materials should not be greater than 20°C, and the materials should be chemically compatible.

Shear joints

Joint design is vital for successful welding. The basic shear joint works very well for semi-crystalline materials such as fluoropolymers, yet it works the best for cylindrical parts where it can produce a strong, airtight weld. The shear joint has a relatively large melt area and therefore needs more power, greater vibration amplitudes or longer weld times than other joints.



Basic shear joint for ultrasound welding

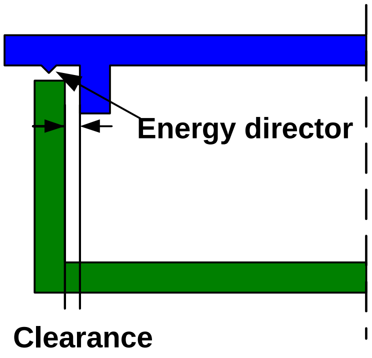
Joints should be provided with location recesses to give good alignment before welding and supported during welding to prevent flexing and a poor weld. Where large welds are required it is advisable to design the joint to have "flash wells" - small recesses where the flash is both contained and concealed.

Butt joints

Butt joints are simple to design but melting often demands a high-energy input for their large areas. Typically, a V-shaped "energy director" is placed on one of the surfaces to reduce the initial contact area between the joint faces and to concentrate the ultrasonic energy at the energy director. This gives high initial heating and melting.

With amorphous plastics, the energy director melts and flows across the face of the joint to create the weld.

With semi-crystalline materials, the narrow flow temperature range often makes it difficult for the energy director to flow across the face of the joint, and this can result in a weak weld. For this reason, semi-crystalline materials often need high energy levels and long cycle times to get melting across the full joint.

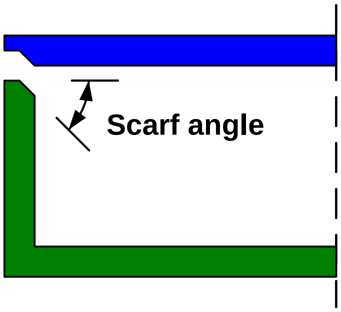


Basic butt joint for ultrasound welding

As with shear joints, butt joints should be provided with location recesses or other methods to give good alignment.

Scarf joints

Scarf joints are particularly good for semi-crystalline materials such as fluoropolymers, because melting occurs over the full weld face thereby removing the need for the melt to flow through the joint. The two parts of a scarf joint have matching angled faces (in the range 30° to 60°), and the angled face increases the available melt area. High scarf angles are better for thin-walled products to maximize the contact area.



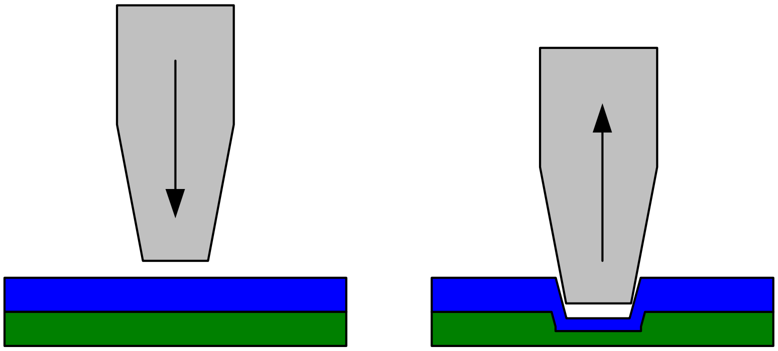
Basic scarf joint for ultrasound welding

Staking or swaging

Ultrasonic welding can also be used for staking (similar to hot air staking) except with ultrasound the horn is specially shaped to melt the top of the stud and form it into a rivet-like head. Ultrasonic staking works best with a rivet head height not less than half the stake diameter.

Spot welding

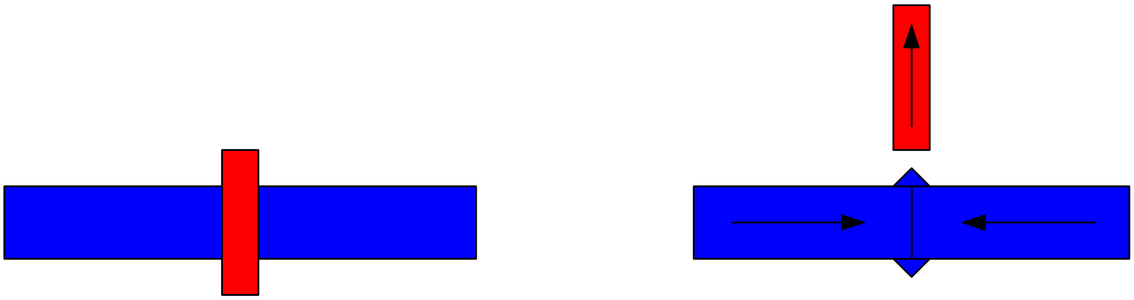
Ultrasonic spot welding can be used to join parts together and does not need preformed holes or energy directors. The ultrasonic horn has a pilot tip that directs energy to a spot on the top sheet and melts through the top sheet and into the bottom sheet. Some of the molten material from the top sheet is carried into the bottom sheet where it bonds to form the spot weld. The underside of the spot weld remains smooth.



Typical ultrasonic spot weld

Hot plate welding

Hot plate welding uses a heated flat plate to melt the joint surfaces but is generally only used for joining like materials due to the need for both materials to melt at the same temperature. The parts are held against the hot plate until the surfaces melt, the hot plate is withdrawn and the melted surfaces then are pressed together to create the weld that is held under pressure until it has cooled enough for handling.



Hot plate heats two plastic parts

Hot plate removed and plastic parts pressed together to form weld. Sprue forms at contact points.

The basics of hot plate welding

The hot plate is usually electrically heated and is covered with a PTFE coating to stop the plastics from sticking to it during the process. Most materials can be hot plate welded, but polyamides and other materials with a tendency to oxidize when heated in-air should not be hot plate welded.

Joint designs can be very basic, and the only difficult factor is the creation of the sprue of molten material during the welding process. In vinyl window production, this is removed manually, but in other cases, ”flash traps” can be provided to reduce post-welding handling. In most cases, the cycle time for hot plate welding is longer than that for ultrasonic welding.

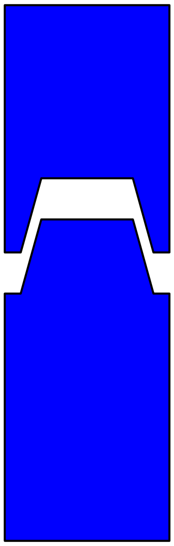
Friction welding

In friction welding, heat is generated by contact between a moving part and a stationary part. After friction is produced at the contact faces, melting will be used to form a bond or weld. In many ways, the mechanism of melting is similar to that of ultrasonic welding. Where the joint is circular, a rotary motion can be used. This process is termed ”spin welding,” where the joint is rectangular or irregular. When a linear or an orbital motion is used, the generic term ”frictional welding” is used.

Spin welding

Spin welding is a special kind of frictional welding for parts having circular planar joint faces with a common axis. The parts are brought together under pressure, and one is held stationary while the other is rotated about the common axis. When the friction between the parts has melted the joint faces, the rotation is stopped and the parts are held together until the joint has cooled.

Spin weld joints generally have a V-shape to increase the weld face area and will often include” flash traps” to trap flash from the process.



Typical shape for a spin weld joint

Rectangular or irregular parts

These types of joints require either linear or orbital motion to create the frictional weld.

In the case of linear motion, one part of the joint is fixed, and the other part is reciprocated on a single axis under pressure to generate frictional heat. The joint surface must be flat in the axis of movement but can be curved across the axis. To prevent parts snagging, the joint faces must never completely come out of contact, and there always must be a small overlap between the joint faces.

Vibration frequencies are in the 100 to 300 Hz range, and the lower the frequency the higher the displacement used in the linear motion. When pressures of 0.5-5 MPa are used, the total cycle time (including cooling) is in the region of 2-3 seconds.

For very thin walled parts, orbital welding is more suitable, where the quick movement of one of the parts in a small circular motion generates the frictional heat.

Induction welding

Induction welding requires a magnetically-active bonding agent or material inserted at the joint interface. The bonding agent is usually a thermoplastic material containing ferromagnetic particles but can also be a metal foil, fabrication or stamping. Despite this, it is usually iron or stainless steel.

When the bonding agent is exposed to a frequently alternating magnetic field, the ferromagnetic particles vibrate rapidly as they attempt to align atomically with the magnetic field. This quickly generates high local heating, and the bond area can reach melting temperature in as little as two seconds.

The parts are assembled and held under low pressure with the bonding agent trapped in the joint. Then, they’re exposed to the magnetic field, which melts the area around the bonding agent. The pressure is increased to force the molten agent material throughout the joint, where it contacts and melts the joint surfaces, and bonds to them on cooling.

Typical joint designs are those that can confine the molten bonding agent (e.g. tongue and groove), shear and step joints.

Laser welding

Laser welding uses a laser beam to raise the temperature above the melting point at the interface of the parts to be joined. The process works by having one of the materials transparent to laser radiation (800 nm to 1100 nm), while the other absorbs the radiation. The transparent material allows the laser light to pass through it with little absorption. When the laser reaches the laser opaque (energy absorbent) material, the energy heats the joint interface and allows the weld to form. Ideally, almost all of the energy should be absorbed at or near the surface of the energy absorbent material.

Lasers can be used to weld almost every kind of thermoplastic, including dissimilar plastics (if the melt temperature ranges overlap). However, one of the joint materials must be transparent to laser radiation while the other absorbs the radiation. Suitable pigments can modify the transparency and absorption characteristics of most polymers with little effect on the visible light transparency and absorption characteristics.

The very specific application of the heating allows for simple joint design with no need for ”flash traps” and the low power required makes laser welding suitable for very large and very small parts, for clean applications, and for assemblies with delicate components.

Summary

The variety of available plastics welding methods have proven to serve almost all industrial needs. Most plastics are easily welded with at least several methods, which allow real choice in the economics of the particular part and process. Many of the plastics products we use on a daily basis use one of the welding methods described in this Newsletter, and welding will continue to be one of the major methods of fabricating plastics products in the future.

The available plastics welding methods can serve a host of industrial needs. However, welding thermoplastics can be difficult, and shouldn't be left to just anyone. It takes a company with experience and the technical know-how to make it work. And that company is Zeus.

Please note: Welding plastics can create harmful fumes, so all welding applications should be executed in a well-ventilated area to avoid injury.

How Zeus Can Help

With a technical inside and outside sales force backed up with engineering and polymer experts, Zeus is prepared to assist in material selection and can provide product samples for evaluation. A dedicated R&D department staffed with PhD Polymer chemists and backed with the support of a world-class analytical lab allows Zeus an unparalleled position in polymer development and customization.

Since 1966 Zeus has been built upon the core technology of precision extrusion of high temperature plastics. Today, with a broad portfolio of engineered resins and secondary operations, Zeus can provide turnkey solutions for development and high-volume supply requirements.

Don’t miss the next whitepaper

Go to **http://www.zeusinc.com/newsletter** and sign up to receive our monthly technical e-newsletter so you won’t miss the next whitepaper topic.

Contact Us

Visit us at **http://www.zeusinc.com** for more information about our products and capabilities, or give us a call at (toll-free) **(866) 272-4118** or (international) **001.803.268.9500.**